On the Extinction of Colour by Reduction of Luminosity.

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In "Colour Photometry," Part III, § XLVII, 'Phil. Trans.,' 1892, the results of some measures for the extinction of colour from the spectrum colours are recorded and the method of making the observations is explained. What was attempted in these observations was to reduce all the colours to a hue of the steel grey which a pure white becomes when it is of feeble intensity. During the observations then made it was found that some rays near the yellow lost their colour earlier than shown, but that the white they then matched was not completely the steel grey alluded to above. In the present results the hue of the white has been disregarded and no judgment of the hue of the white was required, making it easy for anyone to go through a series of readings.

The instruments used were almost the same in principle as those employed on the previous occasion, but in some details they differed. Instead of sectors being employed to dim both colour and white, the annulus described in my paper on "The Sensitiveness of the Retina to Light and Colour"* was employed, and the figure from that paper is inserted here to show the apparatus, as is also its brief description.

A hole is pierced exactly at the centre of the circular disc as shown in F. The disc of glass A is also pierced with a hole in its centre, the hole being just of the size sufficient to allow a pin with a screw thread springing from a brass plate attached to the wooden slide to penetrate. The disc of glass F is pressed on to the pin and the two glass plates are clamped together by a mill-headed nut D; a washer of paper E being placed between the two. The disc A is cemented into a circular ring B graduated into degrees. On A is ruled a line joining the centre and the zero of graduation. The junction of the most opaque and transparent parts of the annulus is made to coincide with the zero point and the line ruled on A. In the wooden slide is placed a metal slit S with movable jaws opening centrally. When vertical, the line ruled on A passes through the centre of S. The brass circle C can be caused to move round its centre by a thread passing over it and a small toothed pulley, to which is attached a long arm B which can cause the pulley to rotate when it is turned.

The annulus, the manufacture of which is described in the paper referred

* 'Phil. Trans.,' A, 1897 (vol. 190).

to, has regular gradation for each degree, the coefficient of obstruction (it is not exactly absorption) being 0·0086 for each degree.

The general arrangement of the apparatus is shown in the accompanying

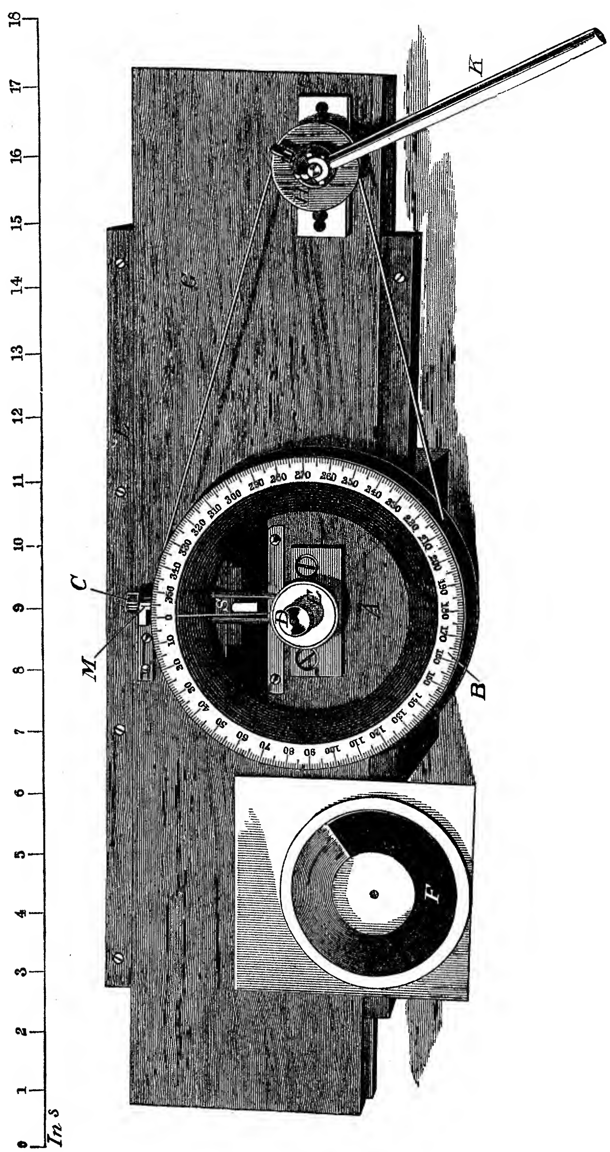

FIG. 1.

figure (fig. 2): G is the extinction box, B is the body of the camera of the colour-patch apparatus, the focus of the spectrum being in the plane C, which is the annulus slide shown in fig. 1. L is the lens which, after reflection,

will form a coloured patch in the interior of the box G into which the ray enters, through a tube K′, after reflection by a mirror M_1. M_2 reflects the ray again to the end of the box. The white beam which is a ray reflected from the first surface of the first prism of the colour-patch apparatus is shown on the left of B, and after passing through a lens L″ it enters the box through K″ after reflection from a plane mirror M_4, and is again reflected by a silver mirror M_3 to the end of the box. R′ and R″ are rods which restrict the beams on entering the box.

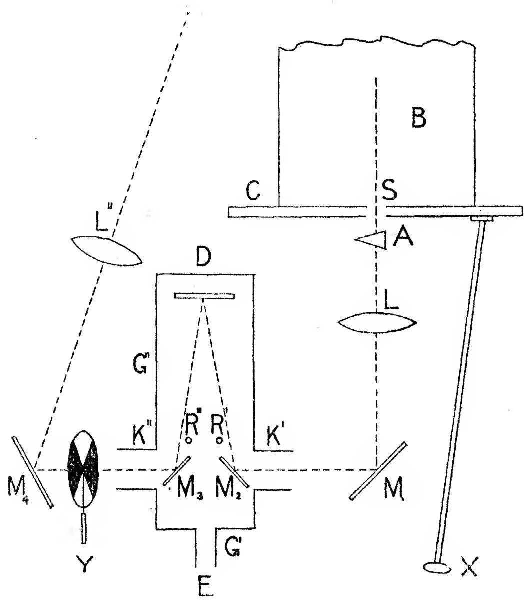

FIG. 2.

The patches of white and colour are viewed through the eyehole E. There is a light-tight lid to the box G which can be opened, and when the apparatus is in a dark room and the light admitted to the spectrum apparatus through an aperture in the wall, this lid can be removed and matches made with both eyes together, otherwise the eyehole has to be employed. It need scarcely be said that G is painted a dead black inside and outside. There is a glass scale, graduated to $\frac{1}{2}$ mm., attached to the annulus slide (not shown in the figure). An image of the scale is thrown, by a lens of short focus, on a distant white screen, on which a vertical line is ruled, passing through the area on which it falls, so that a very small alteration in the position occupied by the slit in C can be observed. The scale numbers of the red and blue lithium, the D and the Mg lines were obtained by volatilising a solution of these substances in dilute HCl in the arc. The different lines of these metallic spectra were caused to pass through the centre of the slit S, and the scale number for each was read and noted. From these the positions of the colours can be calculated. It will be noted that the annulus can be rotated by the observer by means of the long arm X, and the sector opened or closed by the shorter arm Y.

The method of proceeding was first to close the slit of the spectroscope to a convenient width. This diminished the luminosity of the spectrum and also

the reflected beam of white light. The luminosity of the white light compared with the D light was measured and then observations commenced. Any desired ray was allowed to pass through the slit and the annulus rotated until it was judged the colour was gone. It was then compared with the white beam, the sector being opened or closed till it was judged it and the colour had the same luminosity. If the colour did not match the white the annulus was turned and the white again compared with it. When a good match was obtained the scales of the annulus and of the sector aperture were read and noted. In this case it will be seen that only a match with the white in colour and luminosity was required. The spectrum from red to violet was thus examined. The results in the first table and in the next are those obtained by myself and by W. They both are very similar and perhaps some of the lack of perfect similarity is due to slight errors in observation by one or other of us. The annulus readings were reduced by the necessary calculations to a scale in which D, before reduction, had the luminosity of one candle at one foot away from the screen. The scale numbers of the annulus slide was converted into my standard scale numbers (which are taken in all my previous papers on the subject, except in "Colour Photometry," Parts I and II), so that the tables and diagrams can be readily compared with those which appear in previous communications.

The results obtained in no wise entail any alterations in the conclusions arrived at on the same subject, in my paper on "The Sensitiveness of the Retina to Light and Colour."* In that paper it was stated that the point of extinction of a colour depended on the size of the area, when the area subtended at the eye was less than about 4°. If with an area A the illumination required to make the colour disappear was m, with an area $A/16$ the illumination required to cause the disappearance of the colour was increased to $10\,m$. In the same paper it was shown that the extinction of light followed a different law, and that for each ray there was a size of area of colour which, when observed to extinguish colour, would cause the light to be extinguished at the same moment.

These measures which are recorded were only taken when the observer had been in darkness at least a quarter of an hour, and whether the observations were taken at the end of that time or after the lapse of an hour, the same amount of diminution in intensity was necessary for the colour to disappear.

In the two tables the amount of reduction for each ray is recorded which was required supposing the light of D had a luminosity of one candle at one foot off the screen. This is shown in Column IV. In Column V is

* 'Phil. Trans.,' A, 1897.

shown the reduction that would be required supposing *each ray had a luminosity of one candle at one foot distance from the screen.*

I. Scale No.	II. λ.	III. Luminosity of spectrum of normal brightness.	IV. Reduction required for colour to disappear when D = 1 candle.	V. Reduction required when every colour has a luminosity of 1 candle.
62	6957	2	0·075	0·00150
60	6728	7	0·023	0·00161
58	6521	21	0·008	0·00168
56	6330	50	0·0035	0·00175
54	6152	80	0·0017	0·00136
52	5996	96	0·0014	0·00136
50	5850	100	0·0016	0·0016
49	5783	100	0·0025	0·0025
48	5720	97	0·0074	0·0072
47	5658	92	0·0061	0·0056
46	5596	87	0·0034	0·00295
44	5481	75	0·0027	0·00202
42	5373	62·5	0·0023	0·00144
40	5270	50	0·0019	0·00095
38	5172	36	0·0017	0·00061
36	5085	24	0·0018	0·00043
34	5002	14·2	0·0025	0·00035
32	4927	8·5	0·0036	0·00031
30	4848	5·7	0·0049	0·00028
28	4776	4·0	0·0060	0·00024
26	4707	2·8	0·0075	0·00021
24	4639	2·0	0·0105	0·00021
22	4578	1·4	0·0165	0·00023
20	4517	1·1	0·0240	0·00026
18	4459	0·86	0·0320	0·000275
16	4404	0·70	0·0430	0·000301
14	4349	0·56	0·0540	0·000302
12	4296	0·45	0·0700	0·000315
10	4295	0·35	0·0950	0·000332
8	4198	0·26	0·1300	0·000328
6	4151	0·19	0·1700	0·000326
4	4106	0·14	0·2400	0·000336

W.'s Curves.

I. Scale No.	II. λ.	III. Luminosity of spectrum.	IV. Reduction required for colour to disappear when D = 1 candle.	V. Reduction required when every colour has a luminosity of 1 candle.
62	6957	2	0·056	0·00112
60	6728	7	0·014	0·00098
58	6521	21	0·005	0·00105
56	6330	50	0·0028	0·00140
54	6152	80	0·0017	0·00136
52	5996	96	0·0013	0·00125
50	5850	100	0·0017	0·00170
49	5783	100	0·0027	0·00270
48	5720	97	0·0060	0·00582
47	5658	92	0·0032	0·00294
46	5596	87	0·0018	0·00156
44	5481	75	0·0014	0·00105
42	5373	62·5	0·0013	0·00081
40	5270	50	0·0014	0·00070
38	5172	36	0·0017	0·00061
36	5085	24	0·0021	0·00050
34	5002	14·2	0·0025	0·00035
32	4924	8·5	0·0033	0·00028
30	4848	5·7	0·0043	0·000255
28	4776	4·0	0·0052	0·000208
26	4707	2·8	0·0058	0·000162
24	4639	2·0	0·0070	0·000136
22	4578	1·4	0·0080	0·000112
20	4517	1·1	0·0110	0·000121
18	4459	0·86	0·0150	0·000129
16	4404	0·70	0·0230	0·000161
14	4349	0·56	0·0330	0·000185
12	4296	0·45	0·0430	0·000203
10	4245	0·35	0·0540	0·000189
8	4198	0·26	0·0650	0·000169
6	4151	0·19	0·0700	0·000133
4	4106	0·14	0·0800	0·000112

The following shows part of a series of readings, and is given to illustrate the closeness of the different observations made :—

Scale No.	Readings of the annulus.	Mean of readings.
62·7	35 40 36	37
60	145 135 130 130	135
57·35	197 198	197
54·62	230 250 240	240
51·95	250 235 255 248	247
50·87	235 238 250 230 235 248	238
50·33	230 227 250 255 262	245
48·25	163 172 180 190 190 190	183
47·63	221 228 220	223
45·47	230 243 245 250 225 245 255	241

In the case of the whole series of readings, the D light of the spectrum through the thinnest part of the annulus was 0·145 candle at one foot off the

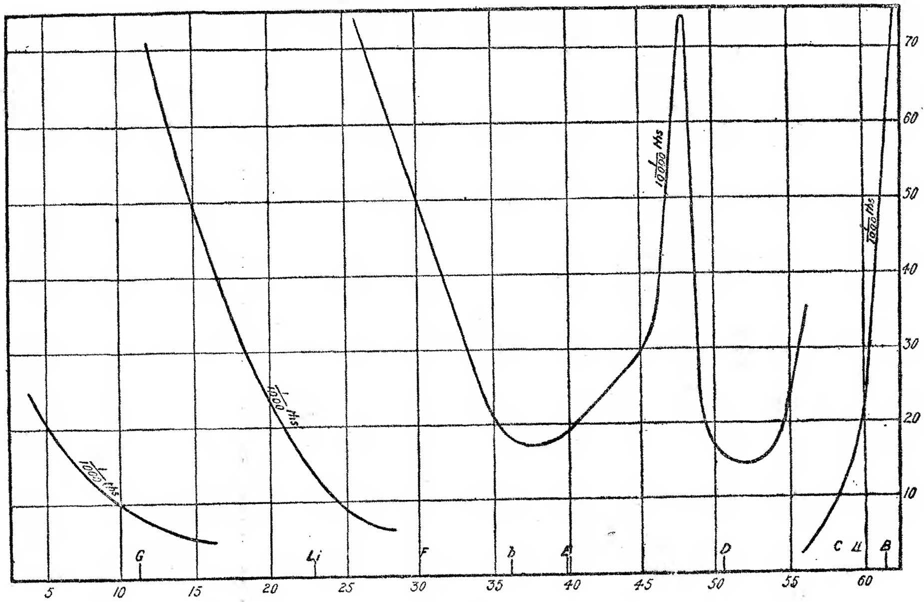

Fig. 3.

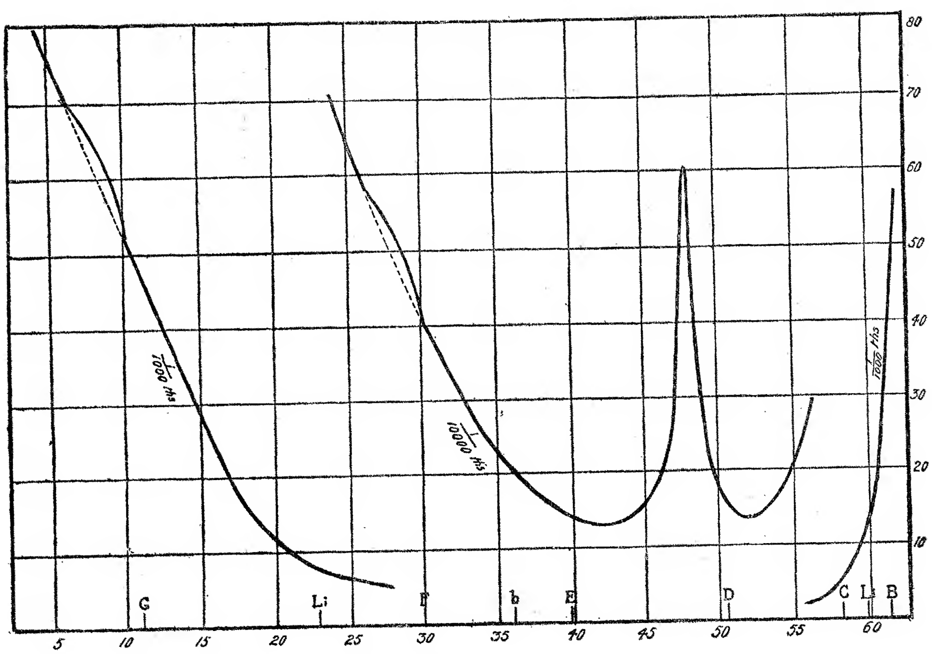

Fig. 4.

screen. The mean readings were taken, and then, as before stated, transformed into the result that would have been obtained if the D light had been one candle at one foot from the screen. Several separate series were taken and the mean of the means adopted for each scale number.

The tables and diagrams show that the reduction of colour to match the white depends, at each end of the spectrum, on the extinction of one of the three sensations, and intermediately with the reduction or extinction of one of the sensations. In the red, beyond Scale No. 58, the extinction of the colour of a luminosity of one candle at one foot distant from the screen is affected when the luminosity is reduced to about 0·0016 candle, and the blue sensation is extinguished when its luminosity is reduced from one candle to closely to 0·00009 candle. From observations made by a red blind person, it was found that the green sensation of a similar luminosity was closely 0·0005 candle. The whole of the spectrum rays were matched with white by this observer, and in the green, of course, he matched a large portion with full white or with very slight reduction in luminosity.

There is one point that requires notice, and that is that the pinnacle of the sudden rise in the matching of the white with the colour takes place exactly at the same wave-length Scale No. 48·7 (λ 5772) as that in which the red and green sensation curves of equal stimulation cut one another. This wave-length was also referred to in my paper read before the Society on November 25, " On the Change in Hue of Spectrum Colours by Dilution with White Light." There is a connection between the results of the observations therein made and those in the present communication.

These two sets of what may be termed minor measures of the various " qualities " of the spectrum and its different colours, again go to prove the validity of the three-sensation theory of colour vision, and are at variance with the theory which makes sensations go in pairs.